Source Term Balance for Finite Depth Wind Waves

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LONG-TERM GOAL

The long-term goal is to obtain closure of the energy balance equation for wind wave evolution in finite depth water by means of direct measurement of the main source terms. These source terms represent the basic physical processes required to develop reliable finite depth wave prediction models.

SCIENTIFIC OBJECTIVES

The objectives are to establish a description of the basic sources/sinks of energy responsible for shallow water wind wave evolution, namely dissipation due to both wave breaking and bottom friction, and wind input. Spectral distribution of "white-capping" dissipation has not previously been obtained either experimentally or theoretically, and currently speculative approaches are used to represent this term in wave models. The natural phenomena determining this term are random, non-linear and related to extreme wave conditions and hence are difficult to evaluate in the field. The other two terms have been the subjects of intensive research during the last three decades, although detailed field observations are rare. There is a qualitative understanding of their behaviour, however, no established quantitative description is available.

APPROACH

An experimental site at Lake George near Canberra, Australia has been established. The Lake is a shallow water basin and closely approximates the idealised case of finite depth fetch limited growth. The experimental site includes an observational platform with a shelter to accommodate electronics and equipment as well as researchers during observations. An anemometer mast, accommodating 3 wind probes at 10 m and 5.65 m elevations over the water surface, was erected 10 m from the platform to avoid disturbance of air flow with a measurement bridge between the platform and the mast. Another anemometer mast, accommodating 5 wind probes at four heights closer to the surface, was set 6 m off the bridge to ensure undisturbed airflow for these lower anemometers. The bridge is used for the majority of the wave measurements. Two shelters constructed onshore provide basic storage and accommodation for researchers during their stay at the site. The location has vehicular access, a simple offshore bathymetry and water of approximately 1.3 m depth within 50 m of the shoreline. The platform, located approximately 50 m offshore is shore-connected with an elevated walkway and is thus accessible in any weather conditions. Computer facilities allow for preliminary data analysis to be performed on the spot though the main data processing will be done at the Australian Defence Force Academy (ADFA). The site is located approximately one hours drive from ADFA and measurements are carried out whenever meteorological forecasts are appropriate.

To measure "white-capping" dissipation, four different but integrated instrument systems are being employed. Since individual waves naturally change their heights while propagating within irregular wind wave groups, direct in situ estimates of energy lost by breaking waves are being attempted in terms of the integrated group energy, measured with an array of capacitance wave probes. The array also allows measurement of directional wave spectra. Two additional mobile wave probes can be positioned to measure spatial decay of breaking wave groups. An observer can also mark data records electronically, in response to visual observations of breaking. Facilities for quick in situ calibrations of the wave probes are available. Three Acoustic Doppler Current Meters (ADV) are employed for simultaneous measurement of dissipation rates through the water column in the vicinity of the array. An underwater hydrophone, the output from which is related to both the strength and dimension of breakers, is located on the bottom beneath the array. Video recording of the surface spot around the array is used to identify breaking events and to supply information on the spatial dimensions of white-capping. The logging of all systems is synchronised.

Simultaneously, measurements in the atmospheric boundary layer are also being conducted. The anemometer masts have six cup anemometers logarithmically spaced from 0.5 m to 10 m and two wind direction vanes. The data logging is synchronised with the wave and breaking recordings. In addition to the wind profile measurements, a sonic anemometer is also deployed on one mast to provide direct estimates of the momentum fluxes. A wave following pressure system, developed by M. Donelan will be deployed prior to or during the 1999 winter (August-October) to explore wave-induced stresses and pressure fluctuations in the atmosphere.

It was initially proposed to measure the bottom shear stress with a bottom mounted shear plate. Preliminary tests, however, indicated that the mud bottom of the lake will not be suitable for this instrument (a laboratory version is operational). Hence, it is now proposed to collaborate with T. Stanton to measure the bottom friction term with a high resolution Doppler profiler.

Full analysis of the data will include a modelling phase, in which the EXACT-NL model of Hasselmann will be used. The model will be forced with the source terms measured at the experimental site and spectral evolution compared with the comprehensive data previously obtained at the Lake George site (Young et al., 1996).

WORK COMPLETED

The experimental site at Lake George is fully operational and regular measurements have been carried out for more than a year. Based on the experience gained at the site, several improvements were made during the year.

- Some flow disturbance, caused by the measurement bridge was observed in initial atmospheric boundary layer measurements. Hence, an additional anemometer mast was constructed at a position 6m from the bridge. This mast now accommodates the 5 lowest wind probes. Data from this mast appears to be free of any flow disturbance.
- The deployment system for the directional array has been redesigned for more efficient operation.
- Water temperature was previously measured manually. An automatic system has now been established and data logging integrated with the other instruments.

The photographs below show two views of the Lake George site. The photo on the left shows a general view of the site with the onshore shelters in the foreground and the observational platform in the background. The second photo gives an offshore view of the platform, the measurement bridge and the two anemometer masts. The deployment system for the wave array can be seen in the middle of the bridge. A comprehensive set of photos showing all facilities and instrumentation at the site can be viewed on the Lake George Project web site.

Data accumulated to date comprises approximately 2Gb in digital form as well as 21 SVHS video tapes.

All data, including the SVHS video tapes are synchronised. A sub-set of this complete data set has been analysed and is available for distribution on CD. A data summary of the complete data set is being developed and transfer of the full data set to CD will shortly occur.

Initial planning involved the conduct of a major integrated experiment at the site during August-September, 1998. However, due to the very strong El Nino of 1998 rainfall in the area was extremely low. As a result, the lake level dropped to a point where this experiment was cancelled. With the end of the El Nino, rainfall has been high and the lake level has increased significantly. At the time of writing, the level was approximately 1m and long term weather forecasts are for above average rainfall for the next three months. Hence, the integrated experiment will now be conducted in September of 1999.

The data have been actively used for scientific research and some results were presented in two papers at the WISE-5 meeting in Belgium in May, 1998 and at a number of seminars in Australia and America. A journal article is being prepared and a brief summary of the most significant results is given below.

RESULTS

Of the source/sink functions responsible for wave evolution, the "white-capping" dissipation term is the most poorly understood. Hence, initial analysis of the extensive Lake George data set has focused on the study of the properties of wave breaking. The major goals are:

1. to find reliable techniques for the detection of breakers in the records by instrumental means and without the use of subjective criteria and
2. to study breaking statistics as a function of spectral properties

The concentration on spectral measures of breaking statistics is aimed at implementation in spectral wave prediction models. Both goals have been accomplished for the dominant waves in the spectrum and some novel results have been achieved.

The acoustic signature of the breakers, as recorded by the hydrophone has been used as an objective measure of breaking. Spectrograms below (Fig.1) clearly show breaking events as local maxima which span a frequency bandwidth in excess of 4 *KHz*. The breaking events shown in the spectrograms have been confirmed by visual inspection of video records.

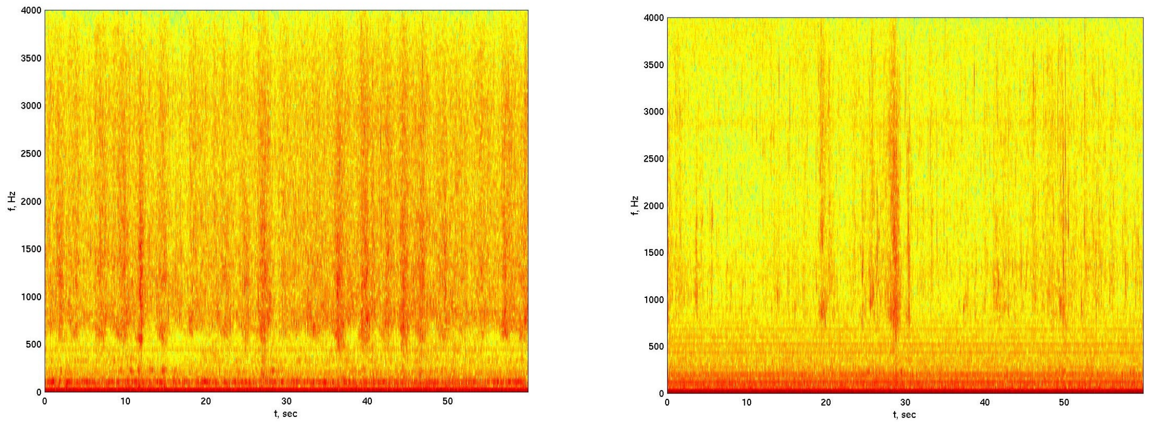

Fig.1. One minute spectrograms of the wave acoustic data. The signatures of breaking waves can clearly be seen as the local maxima (dark regions). Left: An episode of 14 breaking waves which occurred under U_{10}=19.8 m/s wind at f_p = 0.37 Hz peak frequency and H_s = 0.46 m significant wave height. Right: An episode of 3 breaking waves which occurred under U_{10} = 9.3 m/s wind at f_p = 0.39 Hz and H_s = 0.25 m.

The study of the breaking probability *P* of dominant waves in terms of the number of breakers per peak wave period revealed:

1. A strong dependence of *P* on the spectral peak wave steepness ε.
2. The existence of a threshold value of ε, below which no breaking occurs at the spectral peak.
3. A marginal dependence of *P* on the relative water depth H_s/h, a vertical current shear parameter τ, and wind forcing as measured by the non-dimensional peak frequency ν.

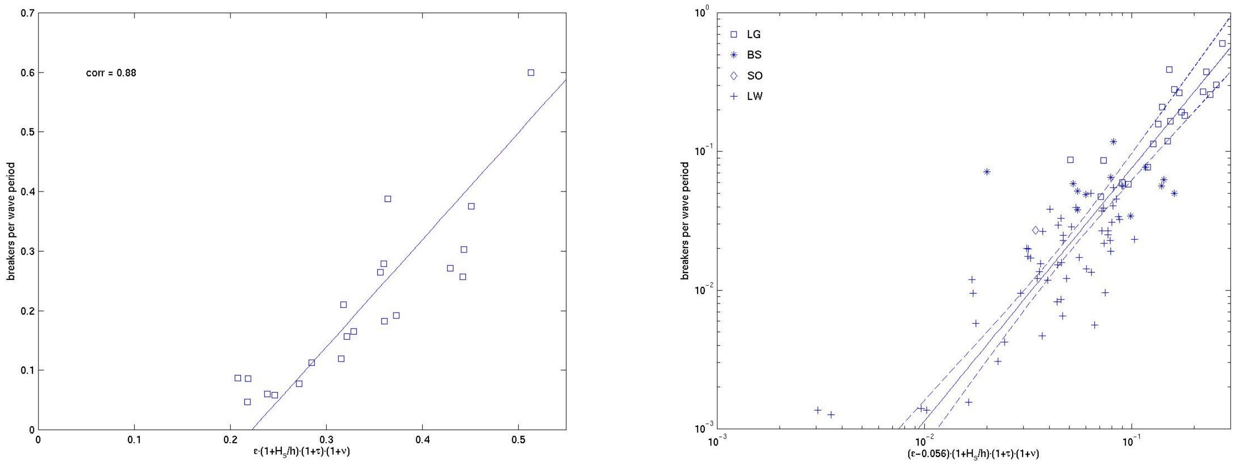

Fig. 2. Dependence of the number of dominant waves breaking per peak period on a wave field parameter consisting of a combination of the steepness, relative depth, shear stress and wind forcing characteristics. Left: The Lake George finite depth results. Right: The Lake George results compared with available deep water data.

Fig. 2 shows a clear dependence of the number of breaking waves on properties of the wave field. In addition, when compared with deep water results, the data clearly show that the enhanced steepness of finite depth waves leads to a significantly higher proportion of breaking waves. It is interesting to note, however, that the same functional dependence holds for both deep and finite depth conditions.

IMPACT/APPLICATION

Results of the field research and parameterization of the source terms will have potential impact in a number of areas.

1).Wind Wave Dynamics. Direct, simultaneous, in situ field measurements of the major source terms together with detailed knowledge of the spectral evolution have not previously been attempted. The results have the potential to provide considerable insight to present understanding of wind wave evolution in finite depth water.

2).Wave Modelling. Source terms presently used in finite depth wave prediction models are largely extrapolated from deep water experience. Direct measurement of the source terms in such situations will provide a more appropriate representation for the physical processes in such models. As a result, an enhanced ability to predict nearshore wave conditions should result.

TRANSITIONS

Two groups have expressed interests in using the Lake George facility and two groups intend to use results of the experiment for verification of their theoretical models.

Tim Stanton from the Naval Postgraduate School, Monterey, USA will collaborate in the program by providing their bottom boundary layer profiler and bistatic system for the measurement of the bottom boundary layer.

Murray Smith from the National Institute of Water & Atmospheric Research, Wellington, New Zealand is intended to use their microwave backscatter radar system in collaborative investigations of the dissipation due to wave breaking.

Vladimir Makin from the Royal Dutch Meteorological Institute, De Bilt, The Netherlands plans to provide theoretical interpretation using data of observed distributions of mean and wave-induced stresses by means of his wind-wave coupling model.

Linwood Vincent and Donald Resio of CERC are combining the high resolution spectra measured at the Lake George site with other finite depth data to study the detailed form of the finite depth wind wave spectrum.

RELATED PROJECTS

This project will be coordinated with the other DRI experiments planned for Duck, North Carolina. As the experimental site provides good control over the environmental parameters, it is hoped the experiment may well fill some of the gaps in the larger scale, open ocean DRI measurements. An intensive measurement program will be conducted with an expanded instrumentation system (surface pressure and bottom boundary layer) in September 1999. This will complement the Duck program and should provide valuable additional data in well controlled conditions.

REFERENCES

Young, I.R., L.A.Verhagen, and S.K.Khatri, 1996. The growth of fetch limited waves in water of finite depth. Parts I, II and III, *Coastal Engineering*, **29**

The Project web-site: http://www.ce.adfa.edu.au/research/LakeGeorge/web_html.htm